

ORGANIC PHOTOVOLTAICS

The development of clean alternatives to fossil and nuclear energy is vital for the growth of sustainable economies. One of the most attractive alternatives is photovoltaic (PV) conversion, the possibility to harvest solar energy.

Among the different technologies already available to directly convert solar light into electricity, organic photovoltaics (OPV) - offer several possibilities such as a low weight and a high compatibility with flexible substrates. The fabrication process itself is potentially very versatile, low cost and compatible with mass production via printing processes.

For now, the OPV market is at an early stage of development with the first products being commercialised for niche markets. The low efficiency and short lifetime of OPV hinders its competitiveness against inorganic solar cells. The European position is relatively good in the RTD landscape but also on the industrial side with the presence of several start-ups and large companies (especially chemical companies) focusing on certain segments of the value chain. However, Asian companies hold a strong position in the terms of Intellectual Property Rights (IPR).

This BRIEFING will discuss the need for breakthroughs in PV, technology developments in OPV, their potential impacts on the economy, industry and society, and will also look at the challenges these technologies are facing.

The need for a PV breakthrough

Disruptive breakthroughs in PV are required to develop an unsubsidized market: cost reduction, simple processing and up scaling; higher efficiency & high stability; low energy fabrication, readily available resources and low environmental impact.

Organic Photovoltaics (OPV) and Dye Sensitized Cells (DSSC) could be a promising alternative to silicon (Si) and thin film inorganic-based solar cells, thanks to their comparative advantages : lower weight, compatible with flexible or fragile substrates, and a versatile, easy scalable and low cost manufacturing process.

Nevertheless, even if both DSSC and polymer cells were now commercially available, the competitiveness of organic technologies compared to silicon and other inorganic based solar cells is limited by their efficiency and lifetime within the conventional applications. The efficiency exhibited is still low: around 12% for DSSC, 8% for small molecules and polymer-fullerene BHJ solar cells (values at cell level). Lifetime of small molecules and polymer solar cells ranges from 3 to 5 years, far behind inorganic cells (25 years). The expected lifetime of DSSC cells fall between the two.

(1) Dye Sensitized Solar Cells¹

DSSC is based fundamentally on the use of nanotechnology as the light absorption takes place in dye molecules, deposited on nanostructures. Titanium dioxide (TiO₂), zinc oxide (ZnO) or tin ox-

ide (SnO₂) are mainly used or studied. Nanotechnology provides various ways to diversify the shape of these materials, and then modify the cell properties. Another important issue consists in replacing platinum (Pt) used as a catalyst on counter-electrodes. This can be achieved by depositing nanoparticles of various materials.

DSSC technology suffers from the use of a liquid electrolyte that can lead to solvent leakage and corrosion problems which in turn puts strong requirements on the sealing and impact lifetime. The use of ruthenium dyes is also an issue : it is expensive and not environment friendly.

(2) Polymer Solar Cells

The use of fullerene derivatives like PCBM as electron acceptors has now become standard in high efficiency cells. Research on macromolecular compounds dominates R&D activity for new effective materials in polymer cells (low band gap polymer). Nanotechnology would greatly improve cell efficiency, but up to now, simple mixings are used

(3) Small molecules Solar Cells

Small molecules Solar Cells are built in a p-i-n structure, tandem or non-tandem configurations. Purity and crystalline nature of those molecules can be well controlled leading to a better stability than polymers. Research on efficient molecules synthesis dominates R&D activity.

For both polymer and small molecules solar cells, nanotechnology could have an impact in the

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improvement of the cell's architecture. Polymer and small molecules solar cells suffer from a short life time; this is the reason why developments in encapsulation (humidity and gas barrier) are required.

Impacts

The main characteristics OPV possess compared to other types of PV are low weight, attractive form factor, scalability, flexibility and low cost fabrication. However, as OPV still suffer from low efficiency ratios and short lifetimes, the estimated market entry for OPV-based applications is seen in the mobile off-grid applications. Only after the comparative price throughout the expected lifetime is on-par with other PV types, may OPV gain a share in building integrated and grid-connected applications. However, in term of energy pay back time, a recent study shows that OPV is comparable with the other technologies¹.

Economic

Based on the distinctive characteristics of organic photovoltaics they have the best fit in the mobile off-grid electronics applications, such as OPV-integrated textiles for military purposes or extended use time mobile devices or other applications still to be "invented". Currently these markets are negligible and according to US Energy Information Administration (EIA)³, European Photovoltaic Industry Association (EPIA)⁴, GBI Research⁵, and analysis by Navigant Consulting⁶, they will remain marginal if compared to the existing Solar PV applications. Also the successful cost reductions of metal-based PV cells cut the competitiveness of OPV.

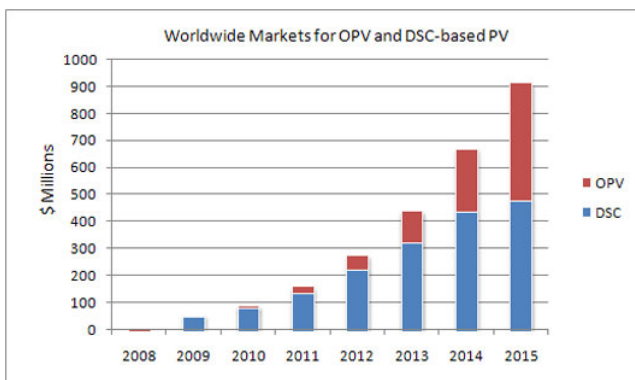


Figure 1: Worldwide markets for OPV and DSC-based PV.

According to EIA, EPIA, and Navigant the off-grid markets currently command 5% of the Solar PV market share globally, mainly through fixed rigid panel installations. Organic photovoltaics have thus the potential for disrupting the existing markets and drive latent needs for more mobile access to electricity. In 2008 NanoMarkets⁷ estimated that the worldwide market for OPV- and DSC-

based photovoltaics could climb to \$276 million by 2012 and reach \$915 million in 2015 as shown in (Figure 1). This estimate is based on the assumption that DSCs can capture a large market share in building integrated PV and thus requires that the technological hurdles have to be tackled quickly and prove DSCs more cost-effective against other building integrated PV solutions.

Technology readiness levels

Although OPV technologies are already commercialised, most of the nano-enabled development proposed to improve their performances have not yet reached the production level. They remain at an applied research or prototype level (Figure 2).

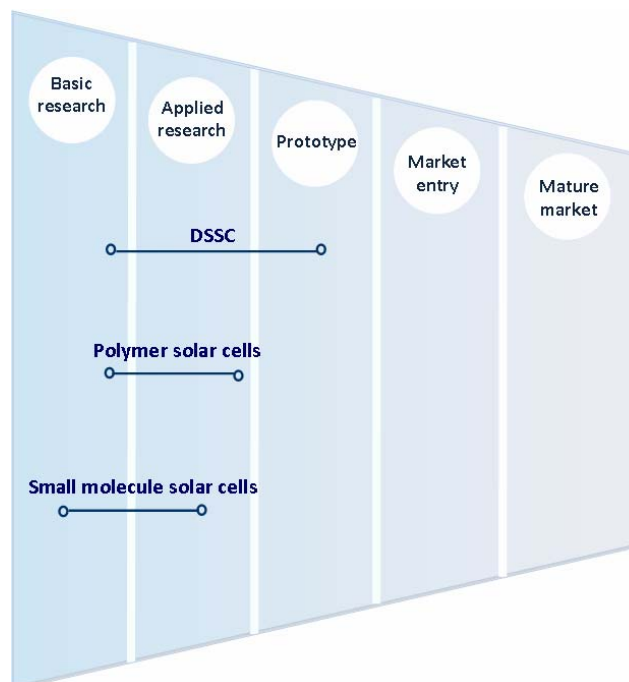


Figure 2: TRL for selected organic photovoltaics.

DSSC

Several organic dyes have been tested as ruthenium alternatives in DSSC, allowing a large range of efficiencies from 4 to 10.1%.

In order to increase the surface and the light absorption coefficient, the shape of the TiO₂ has been modified at nanoscale. Aggregate of nanoparticles, nanorods, nanospheres have been proposed. SnO₂, ZnO (or mixture of the two) have been nanostructured in the shape of nanocrystallines, core shell nanoparticulates or nanowires in order to replace TiO₂ electrodes, efficiency of 8% has been obtained with a nanocrystalline SnO₂/ZnO combined electrode. Solid state DSSC are emerging at the lab level, they have reached 5% efficiency.

Organic solar cells

The use of silver nanoparticles helps the polymer capture a wider range of wavelengths of sunlight

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than would normally be possible. Practically, silver particles are encased in an ultra-thin polymer layer (different than the light-absorbing polymer), which is deposited below the light-absorbing layer.

The use of fullerene derivatives like PCBM allows fast charge transfer and transport to take place at the sub 10-nanometer scale and therefore improve the electron collection.

Industrial actors from varied fields (chemistry, printing, flexible substrates) are increasingly interested in organic cells. Their investment in R&D programmes, and transfer to industry in the next years will be crucial.

Societal Impact on European Citizen

In the first stage OPV and DSSC allow development of novelty consumer goods such as photovoltaic integrated outdoor clothes or mobile devices which may be seen to increase the standards of life. Later on when the technology is developed further, these solar cells may be integrated into construction materials efficiently and the forecasted environmental benefits against the usage of fossil fuels and nuclear power may be obtained. However, for example EIA and GBI do not believe that these secondary developments are likely to occur within the timeframe of the next 25 years.

EHS Impacts

Environment, Health & Safety aspects of OPV applications have been considered by Observatory-NANO WP5 partners⁸. Nanomaterials included in these technologies are generally integrated into a solid host matrix which is encapsulated and are unlikely to be released during normal use of OPV-based applications. While exposure to nanomaterials can occur during the manufacturing stage especially if unbound/free nanoparticles are handled, it is unlikely that human or environmental exposure would occur during use of the final products. Adapted procedures for waste management should however be envisaged in order to avoid uncontrolled release of nanomaterials during disposal/ recycling stage, especially in case of: development of large scale OPV-based construction materials and/or widespread use of OPV-based consumer goods.

Challenges

Concerning DSSC the increase of the lifetime implies up to now an increase in cost. Indeed the use of a liquid electrolyte requires a high quality encapsulation. Moving to solid or gel electrolyte could reduce the need of this high quality encapsulation. A good balance has to be found between increasing lifetime and cost.

The use of ruthenium (Ru) as dye negatively impacts the cost and the environment. Moving to organic dye could overcome these drawbacks. The future of DSSC probably lies in solid state cells with organic dye.

One part of the future of polymer and small molecules cells is in the hand of chemists: they have to synthesise the appropriate (macro)molecular compound able to reach 10% efficiency⁹ with a good stability. The other part depends on the development of a cost effective encapsulation process able to stabilise the cell, from 3 to 5 years today, to 10, then 20 years. The first commercial encapsulation products announced by several companies (Vitex, Tera barrier) are not economically compatible with OPV manufacturing costs.

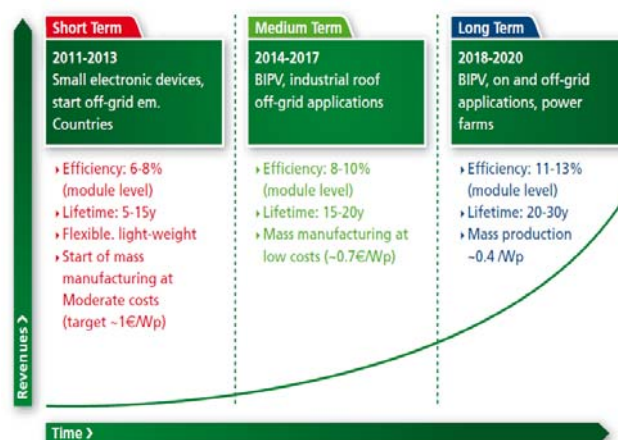


Figure 3: OPV performance forecast (Source SRA OLAE)

Another challenge concerns the production volumes. For now, OPV is dedicated to niche markets and as a consequence to low volume production. The expansion of those markets could lead to an increase of the production volumes implying a decrease of the costs. "On the paper" OPV manufacturing process are potentially low cost, but this has to be confirmed on real cases especially for small molecules solar cells which use a vacuum process step. The goal is to reach in a first step, less than 1 \$/Wp when today, according GTM Report[10], OPV costs 3-4 \$/Wp against 0,9\$/Wp and 1,5-2 \$/Wp for respectively for CdTe and CIGS solar cells. Real competition occurs with inorganic thin films technologies, such as CdTe and CIGS, with similar target characteristics: low weight, relative compatibility with flexible substrate, easy scale up.

Competitiveness in terms of flexibility is questioned as there are companies, such as Nanosolar, developing CIGS nano-ink printable on large area foil. Recently, CIGS solar cells deposited on flexible insulating substrates, have displayed efficiency of 17%. Even Si based solar cells using amorphous silicon could be suitable for flexible applications.

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EU Competitive Position

Due to its early stage of development, the great part of OPV sector activity is still characterized by research activities on fundamentals, materials and integration technologies. Europe is very active at this level (almost 40% of the worldwide publications), and the presence of teams, leaders in their field, like Prof. Grätzel lab at EPFL (for DSSC), is noticeable. For the last few years, efforts have been directed towards structuring the community, amongst other activities through European projects on organic and large area electronics.

On the industrial side, the European position is controversial, while having several R&D oriented start ups [G24i (GB), Solaronix (CH), Solarprint (Ireland), Konarka (Aus/USA), Heliatek (D)] and strong players in the materials supply for the OPV value chain (such as Merck, Solvay, Rhodia), there are, as yet, no published major production investments.



Figure 4: Konarka roll to roll manufacturing process, illustrating the compatibility with mass production.

Summary

- The need for alternative energy sources is obvious. Concerning PV, the development of new technologies such as organic PV to compete with traditional Si technologies, will allow PV to reach new markets.
- To be successful, OPV should firstly open new markets such as OPV-integrated textiles or extended use mobile devices and other still unidentified areas. Once lifetime and efficiency issues are overcome and an affordable manufacturing is reached, OPV will be able to enter the grid connected market in applications such as BIPV.
- Uncertainty is high concerning OPV development because of the importance of the technological competitors like inorganic thin films solar cells.
- EU is the leading world market for photovoltaic

applications. This market demand has been largely driven by subsidized Feed-in-Tariffs for large PV installations. This has also led to formation of a considerable research community focusing on the developments of novel PV technologies in Europe. However, the feed-in-tariff system used in Europe benefits the development of the conventional grid-connected PV over OPV.

- The current trend seems to be that companies are conducting their R&D efforts in within the EU, but setting up the manufacturing capacity elsewhere. This can be seen to lower the future competitiveness of EU in the OPV sector. Also if OPVs are to be integrated into mobile devices, it is quite probable that the manufacturing will take place near the end-device manufacturing.
- There are currently only a limited number (<5) of EU-based companies that have publicly indicated plans for OPV manufacturing within EU. However, EU has strong players in the supportive areas of the OPV value chain, namely materials supply (Merck, Solvay, Rhodia), manufacturing equipment supply, and market delivery actors.

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See also: Organic Electronics Association. "White Paper: OE-A Roadmap for Organic and Printed Electronics, 3rd Edition". 2009.